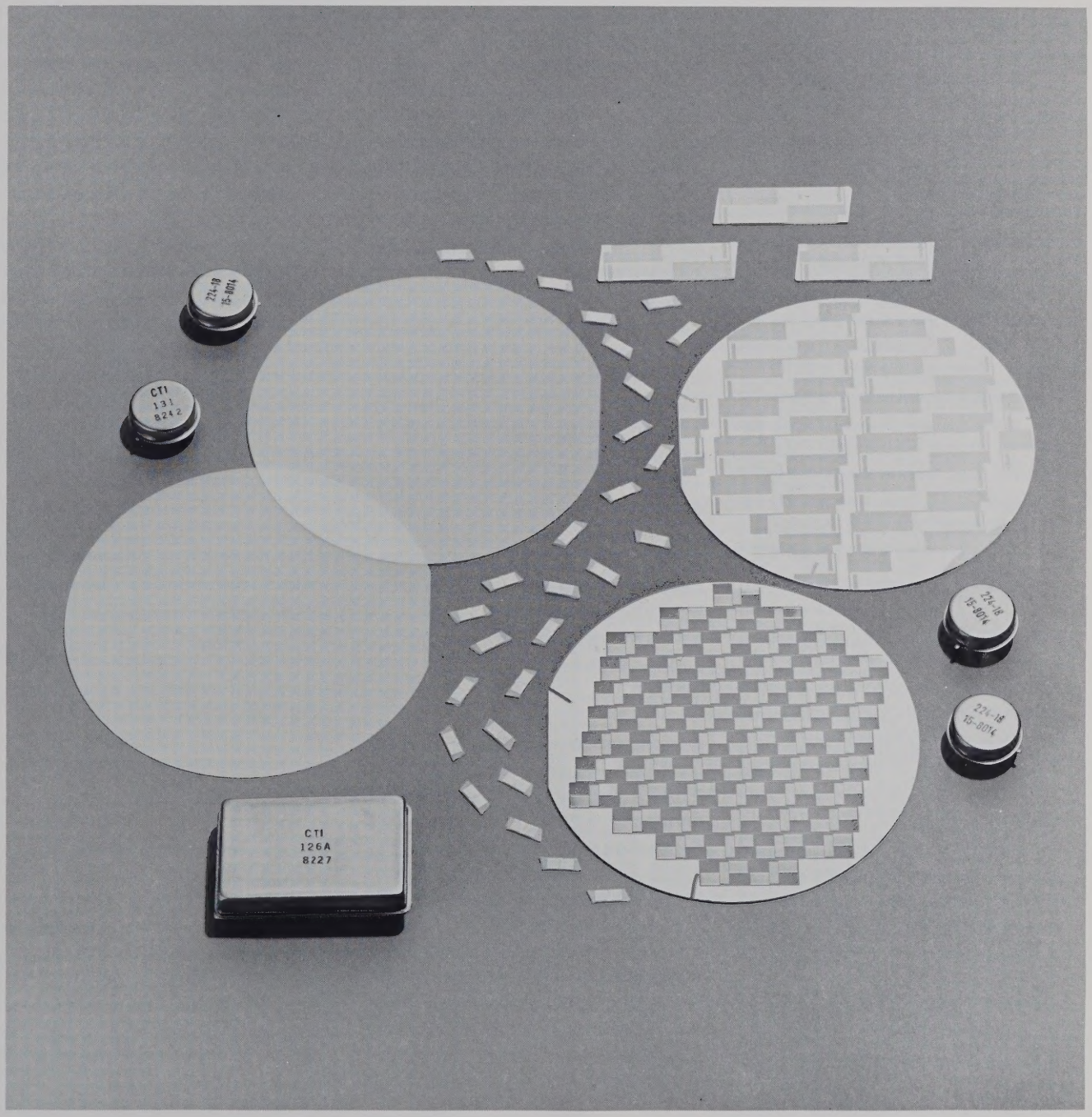
Surface Wave Crystals



Crystal Technology

A Siemens Company

Lithium Niobate
Lithium Tantalate
Bismuth Germanium Oxide

FEATURES:

- **High coupling coefficients**
- **Low propagation losses**
- **Low surface acoustic wave (SAW) velocities**

INTRODUCTION

Lithium niobate, lithium tantalate and bismuth germanium oxide are highly piezoelectric crystals whose excellent properties make them ideally suited as substrates for the generation of surface acoustic waves. These crystals have high surface wave coupling constants, low propagation losses, and low surface wave velocities. Lithium niobate has the highest coupling coefficient of any single crystal material and bismuth germanium oxide has the slowest surface wave velocity.

Although the coupling constants of lithium tantalate are considerably less than those of lithium niobate, the temperature coefficients of velocity for lithium tantalate are less than half those of lithium niobate.

APPLICATIONS

For years lithium niobate has been extensively used in military applications for simple delay lines, filters, encoders/decoders, and compressors/expanders. But more recently surface wave filters fabricated on lithium niobate have been employed as broadcast IF filters in color television receivers. Using lithium niobate as such a bandpass filter, one can obtain a bandwidth of 10% at a center frequency of 44 MHz. Because the spacing of the interdigital transducer fingers is fixed in the metal deposition process, no tuning or alignment is necessary to adjust the frequency and bandpass characteristics of the filter. Lithium niobate filters are also employed as the output modulator filter for video games, video recorders and computer links, while cable television now utilizes a lithium niobate vestigial sideband filter in their modulator.

If the geometry of the transducer array is changed, as by varying the finger spacing along the transducer, the output of the device can be frequency modulated. Thus in an expander/compressor filter set a wide bandwidth pulse is fed into the expander filter to generate a frequency modulated pulse that is compressed at the output transducer. Compression ratios as great as 3000:1 have been achieved in modern radar systems, resulting in improved resolution of the radar target.

In addition to exhibiting linear effects as described above, lithium niobate may be used to generate non-linear effects such as signal correlation and convolution. For example, if two signals that are mirror images of each other (Barker codes) are fed into a lithium niobate decoder, the output will be a sharp pulse which is the convolution of the two inputs. One can also time invert an input signal by its integration over a short time pulse. The output is then the mirror image of the input.

Although the use of lithium tantalate as a surface wave substrate has not been as extensive as that of lithium niobate, lithium tantalate has some desirable properties. Both the yz orientation and the relatively new minimum diffraction cut (MDC) of lithium tantalate have temperature coefficients of delay considerably less than the yz orientation of lithium niobate. Furthermore, the MDC orientation has less beam diffraction by a factor of 20 when compared to isotropic materials, which renders it ideal for filter bank applications requiring a high coupling constant material. Another popular orientation of lithium tantalate is the 112° x-cut, which offers low spurious bulk wave generation in addition to a low temperature coefficient of delay. Lithium tantalate's unique combination of thermal and electro-mechanical characteristics makes it well suited for use in SAW resonators and oscillators. High frequency, temperature controlled oscillators of good stability have been constructed on lithium tantalate, and are now finding application in civil communications systems, especially in digital radio links.

Bismuth germanium oxide (BGO) finds application to long delay lines because it possesses a very slow surface wave velocity. Due to its cubic crystal structure it is nearly isotropic to surface wave propagation, making it feasible to propagate the surface wave at an angle to the crystal axis as well as around curved surfaces of a plate. This enables the construction of a delay line where the surface wave follows a spiral path around the plate,

making the effective length of the delay line many times longer than the physical length of the plate. Using this technique, it is possible to store a complete video frame of information from a TV broadcast. Coupling this long delay line with the appropriate circuitry to form a shift register, the information could then be circulated and stored indefinitely. Only the information which has changed in the television picture need be transmitted in order to update the information stored in the BGO shift register.

More recent work with BGO has resulted in a spectrum of crystal orientations that can provide one with the option of varying the beam steering/diffraction ratio for optimum performance. Of this continuum of orientations, the 40.04° rotated (001) cut, noted in the accompanying data, has diffraction spreading at least two orders of magnitude less than isotropic materials. Compared to the popular (001) cut, (110) propagation orientation, this is an improvement of at least a factor of 70. This particular orientation should be especially significant in the design of both surface wave filters with a high degree of apodization and long time delay devices where minimum diffraction is desired.

PHYSICAL PROPERTIES

	$LiNbO_3$	$LiTaO_3$	$Bi_{12}GeO_{20}$
Crystal Class	Rhombohedral [1,2]	Rhombohedral [3,4]	Body centered cubic [5]
Space Group	R3c or C_{3v}^6 [1,2]	R3c or C_{3v}^6 [3,4]	I23 [5]
Point Group	3mc or C_{3v} [6]	3mc or C_{3v} [3,4]	23 or T [5]
Lattice Constants			
Rhombohedral	a_{Rh} = 5.4944Å [1]	a_{Rh} = 5.470Å [7]	—
	α_{Rh} = 55° 52′	α_{Rh} = 56° 10.5′	—
Equivalent Hexagonal	a_H = 5.1483Å [1]	a_H = 5.15428Å [7]	—
	c_H = 13.8631Å	c_H = 13.78351Å	
Cubic	—	—	a = 10.1455 ± 0.0008Å [5]
Density	4.64 g/cm³ [8]	7.45 g/cm³ [9]	9.232 g/cm³ [10]
Molecular Weight	147.85	235.88	2900.35
Melting Point	1253°C [11]	1650°C [12]	930°C [13]
Curie Point	1150°C	610°C [14]	—
Moh Hardness	5 [8]	5.5 - 6.0	4.5
Solubility	Insoluble in water; practically inert to room temperature acids	Insoluble in water; practically inert to room temperature acids	Insoluble in water; practically inert to room temperature acids
Thermal Expansion Coefficient (0° – 110°C)	α_a = 15.4 × 10^{-6}/°C [15]	α_a = 16.1 × 10^{-6}/°C [15]	—
	α_c = 7.5 × 10^{-6}/°C [15]	α_c = 4.1 × 10^{-6}/°C [15]	—
Thermal Conductivity	1 × 10^{-2} cal/cm-sec- °C [16]	—	—
Electrical Resistivity	5 × 10^8 ohm-cm @ 400 °C [8]	≈ 10^{13} ohm-cm [17]	≈ 10^{10} ohm-cm [18]

MATERIALS CONSTANTS

		$LiNbO_3$ [19,20] (25°C)	$LiTaO_3$ [19] (25°C)	$Bi_{12}GeO_{20}$ [21]
Elastic Constants	c^E_{11}	2.030×10^{11} newton/m²	2.298×10^{11} newton/m²	1.28×10^{11} newton/m²
	c^E_{12}	0.573	0.440	0.305
	c^E_{13}	0.752	0.812	—
	c^E_{14}	0.085	−0.104	—
	c^E_{33}	2.424	2.798	—
	c^E_{44}	0.595	0.968	0.255
	c^E_{66}	0.728	0.929	—
Piezoelectric Constants	e_{14}	—	—	0.99 coulomb/m²
	e_{15}	3.83 coulomb/m²	2.72 coulomb/m²	—
	e_{22}	2.37	1.67	—
	e_{31}	0.23	−0.38	—
	e_{33}	1.80	1.09	—
Dielectric Constants	ε^S_{11}	39.2×10^{-11} farad/m	37.7×10^{-11} farad/m	34.2×10^{-11} farad/m
	ε^S_{33}	24.7	37.9	—

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SUMMARY OF IMPORTANT SURFACE WAVE CUTS [19, 22, 23]

Material	Orientation	Euler Angles (degrees)			Velocity (m/sec)	Coupling Parameter ($\Delta v/v_\infty$)	Temperature Coefficient of Delay (ppm/°C)	Power Flow Angle (degrees)
$LiNbO_3$	41.5°,x	0	41.5	0	4000	0.0277	72	0
	y,z	0	90	90	3488	0.0241	94	0
	128°,x [24]	0	37.86	0	~3990	~0.027	—	—
$LiTaO_3$	—	90	90	112	3295	0.0035	23	1.55
	—	90	90	119.5	3300	0.0037	30	0
	y,z	0	90	90	3230	0.0033	35	0
	—	0	78.5	90	3260	0.0040	31	0
	z,y	0	0	90	3329	0.0059	69	0
	MDC [25]	0	167.1	90	3378	0.0075	64	0
$Bi_{12}GeO_{20}$	(001),(110)	0	0	45	1681	0.0068	~130 [26]	0
	(111),(110)	45	54.7	0	1708	0.0082	—	0
	(110),(001)	65	90	90	1624	0.0037	—	0
	— [27]	45	40.04	90	1827	0.003	—	0

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